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 *Research Needs in Fire Safety for the Human Exploration and Utilization of Space* 

# SPACECRAFT FIRE SAFETY

## A HUMAN SPACE FLIGHT PROGRAM PERSPECTIVE

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# TYPICAL MANNED SPACECRAFT MATERIALS



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## TYPICAL FLAMMABLE HARDWARE PROTECTION



## MATERIALS FLAMMABILITY

- Current ground-based testing conservative but not intolerably restrictive for Shuttle/ISS environments – adequate supply of nonflammable materials for vehicle design to 30% oxygen environment
- Long-term need to quantify “conservative”
  - Relax ISS flammability requirements for payloads, clothing, portable equipment accordingly
  - Future manned space exploration missions extremely weight limited – very desirable to minimize use of nitrogen as consumable by returning to Apollo/Skylab oxygen concentrations



## FIRE RETARDANTS

- **Need a good and easy fire retardant treatment for fabrics (cotton, paper, synthetics)**
  - No significant changes in weight/feel of material,
  - Impervious to washing, dry cleaning
  - Odorless
  
- **Have to compete with current practice of allowing 100% cotton outer clothing (flammable)**
  - Commercially available fire retardants tried with little enthusiasm from crew
    - stiff, dry-clean only, slight odor



## NONFLAMMABLE FOAM CUSHION MATERIAL

- **No good nonflammable foam cushion material**
  - Current choices are Pyrell fire-retardant polyurethane (flammable and life-limited) and Minicell polyethylene foam (more flammable but not life-limited)
  - Both weigh about 2 lb/cu. ft. and are very inexpensive
  
- **Desired cushion material would have following properties**
  - Nonflammable to at least 30% oxygen
  - Lightweight – preferably appreciably less than 2 lb/cu. ft.
  - Not life-limited – life 30 years +
  - Minimal compression set
  - High resilience, tear resistance
  - Negligible particulate formation
  - Open cell for vacuum compatibility
  - Very inexpensive
  - Easy to cut into complex shapes



## **NONFLAMMABLE FOAM CUSHION MATERIAL** **-- EXISTING CANDIDATES**

- **Polyimide Foams (Solimide)**
  - Very lightweight (0.5 lb/cu. ft.), nonflammable in 30% oxygen, not life-limited, open cell
  - Very poor compression set, significant particulate generation, poor “feel”
  - Difficult to cut without generating considerable particulate
  - Very expensive
  
- **Melamine Foams**
  - Very lightweight (0.5 lb/cu. ft.), nonflammable in 30% oxygen, not life-limited, open cell, reasonable compression set
  - Minimal particulate generation but appreciable fine dust
  - Poor resilience, very poor tear resistance
  - Very difficult to cut complex shapes or thin slices
  - Very inexpensive
  
- **Silicone Foams**
  - Expensive, very heavy (at least 6 lb/cu. ft. for adequate resilience)



## **ELECTRICAL WIRE AND CABLE**

- **Critical component from fire safety standpoint, because electrical power is only really credible ignition source (excepting solid-fuel oxygen generators)**
  
- **Key features**
  - Nonflammable to 40% oxygen, resists arc-tracking
  - High resistance to mechanical damage (abrasion, nicks, cuts)
  - High flexibility
  - Lightweight and capable of operating at high temperatures (at least 200 °C)
  
- **No perfect construction**
  - Teflon is heavy and has poor damage resistance
  - Kapton is stiff, has very poor arc-tracking resistance, is easily damaged by nicks, and may degrade in humid environments
  - Tefzel is flammable in enriched oxygen, has limited life above 150 °C and modest damage resistance
  - Teflon-polyimide hybrids currently best compromise for most applications but some aspects inferior to Kapton and others inferior to Teflon



## RUSSIAN SOLID-FUEL OXYGEN GENERATOR (SFOG)



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## GOX IGNITION MECHANISMS

- Two important areas of limited understanding with respect to materials ignition and combustion in oxygen systems
- In recent years, several oxygen system fires have been attributed to a phenomenon christened (possibly erroneously) as “flow friction”
  - Occurs only at high pressures (> 2500 psia)
  - Occurs in pressurized static systems (all other known ignition mechanisms are tied to motion – rapid pressurization, particle impact, friction)
  - Appears to result from leakage through a seal
  - Ignition mechanism not understood, so cannot be controlled by design/materials selection
- Limited studies of particle impact ignition have shown that high flow velocities are required and that metallic particles are probably worse than nonmetals – but we don’t know in any detail:
  - Velocity effects for different particulate contaminants
  - Effects of particle size and quantity
  - Effectiveness of filters as protection (as functions of filter size and filter material)
  - True hazards from gas streams exiting valve seats/orifices at sonic velocity

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## FIRE DETECTION

- **Need capability to distinguish between pyrolysis event and true self-supporting combustion**
  - **Pyrolysis events relatively commonplace and inevitable (electrical shorts, component failures, arcing/arc tracking)**
  - **No true fires on orbit, excepting SFOG, combustion experiments**
  
- **Needs to have high reliability, no false positives**
  
- **Solve conundrum of**
  - **Air flow needed for to transport smoke, combustion products to traditional sensors for fire detection**
  - **Air flow worst thing for microgravity fires**



## FIRE SUPPRESSION

- **Fire suppression capability always for backup only, but needs to be effective backup**
  
- **Issues with Halon-type extinguishers include:**
  - **ECLSS compatibility**
  - **Extinguishant toxicity**
  - **Effectiveness at elevated oxygen concentrations**
  - **Environmental**
  
- **Issues with carbon dioxide (ISS baseline) include:**
  - **Application (where is base of flame?)**
  - **Induced forced convection (will carbon dioxide application extinguish a microgravity fire or stir it up?)**
  - **Mixing (obtaining adequate concentrations in racks)**
  
- **Issues with water-based suppressants (includes Russian segment ISS baseline) include:**
  - **Compatibility with electrical systems**
  - **Clean up**
  - **Use in racks (application to fire source, clean-up)**